A STUDY OF DISPLAY DEVICES FOR FEEDBACK OF MEANINGFUL INFORMATION TO ELECTROENCEPHALOGRAM SUBJECTS

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THESIS

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by

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A Study of Display Devices for Feedback of Meaningful Information to Electro-Encephalogram Subjects

by

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ABSTRACT

In conjunction with the current Bioengineering research program at the Naval Postgraduate School, a study of display devices was conducted. Types of tasking used in electro-encephalographic research were defined, and methods of displaying information in each tasking situation were considered. A special device for display of ASW phonograms was designed and built. Finally, a Vertical Display Indicator Group from an F-111B aircraft was obtained and a simulated cockpit arrangement was designed incorporating this equipment The implementation of this design will provide an advanced format for flight simulation tasking with displays particularly suited to biofeedback.

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I. INTRODUCTION

A. OBJECTIVE

The objective of this thesis is to present a description of methods of displaying information, with particular emphasis on elctroencephalogram (EEG) research. Implementation and evaluation of these methods was in support of a currently ongoing research program at the Naval Postgraduate School investigating the human EEG.

B. EEG GENERATION

The basic functional unit of the nervous system is the individual nerve cell or neuron. This cell is responsible for receiving and transmitting information in the form of an electrochemical pulse or action potential. Figure 1 shows the major structures of a typical neuron. The cell body is termed the soma, and is the location for the features of the cell which are responsible for the basic metabolic processes. The dendritic structure is a lacy network which serves as a receiving structure for an electrochemically generated pulse from preceding nerve cells. The axon hillock serves to sum up the effects from preceding neurons and, when a threshold value has been exceeded, originates an action potential which then travels down the axon. The synaptic terminal region of the neuron serves as an output device for passing the effects of the action potential on to succeeding neurons.

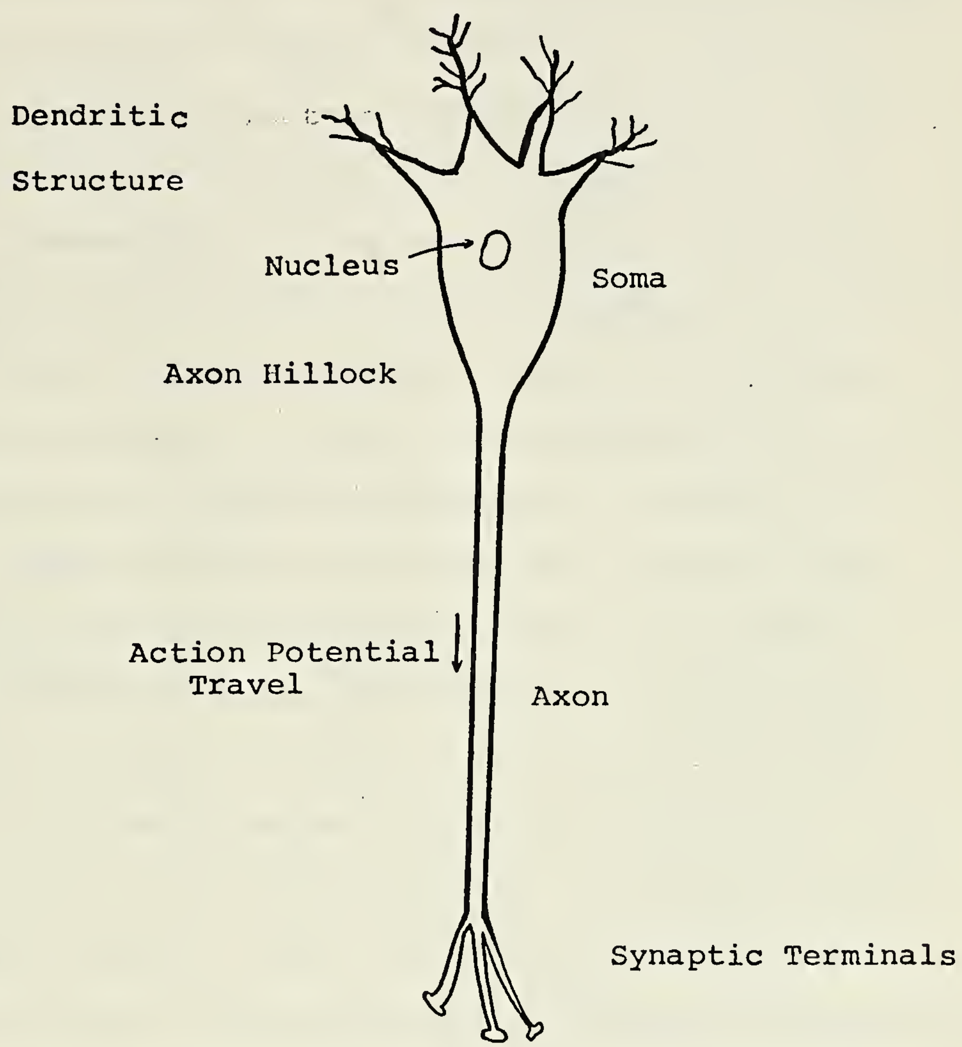

Figure 1. Major structures of a typical neuron.

Figure 2 shows an enlarged view of a synaptic terminal region of a neuron and its interface across the synaptic cleft to the membrane of a succeeding neuron. An action potential arriving through the axon causes transmitter vesicles located in the synaptic foot to release their contents (a transmitter substance) into the synaptic cleft. The transmitter substance then diffuses across the cleft where it affects the permeability of the next membrane. The resting neuron normally has a negative internal potential of 60 to 85 millivolts across its outer membrane, caused by a deliberately created imbalance in sodium and potassium ions in its fluids. The change in membrane permeability caused by the transmitter substance allows positive ions to flow inward, locally raising the cell's internal voltage. This local effect is transferred to the axon hillock by ionic current flow as shown in Figure 3. When the potential at the axon hillock is sufficiently raised, the neuron will 'fire', and an action potential will arise starting at the axon hillock. After a short period of time, the transmitter substance in the synaptic cleft is neutralized by an enzyme, resetting the synaptic terminal and preparing it to repeat the cycle upon arrival of another action potential. [Ref. 5]

From the brief outline of the physiological processes of nerve impulse conduction, one can readily perceive its major characteristics. The transmission of information in a nerve fiber must be one-way due to the operation of the synaptic terminal. The energy for continued transmission

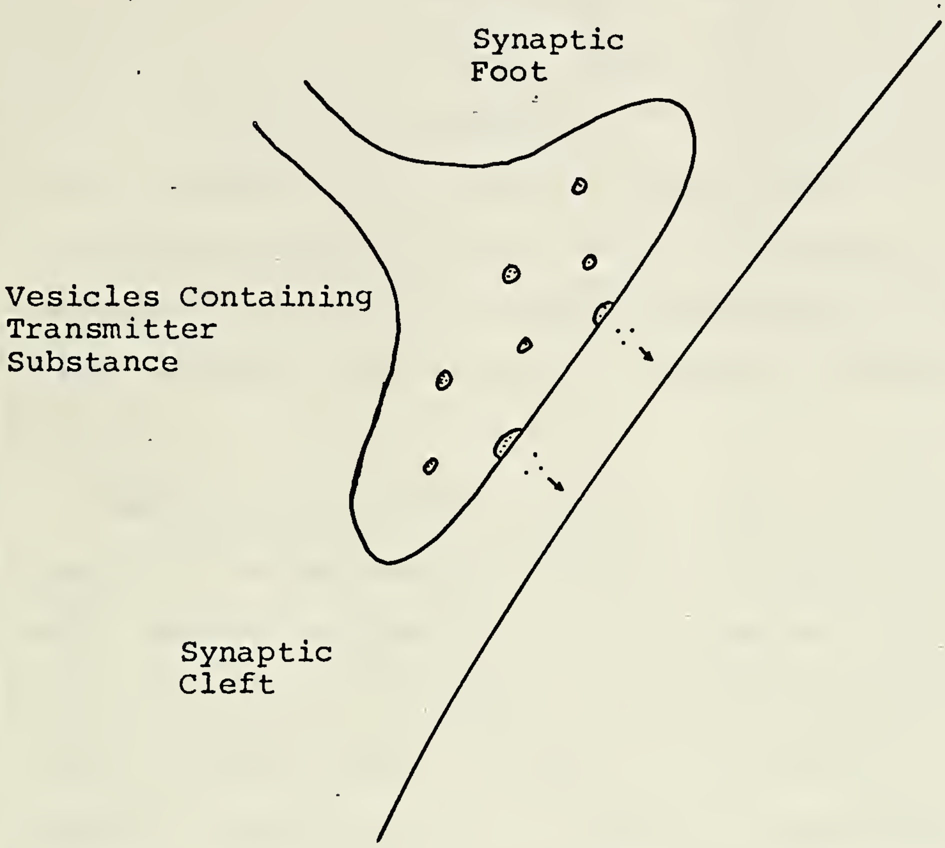

Figure 2. Enlarged view of synaptic terminal region.

of an action potential down a string of neurons is all locally generated energy. Thus, it is not necessary to have a large amplitude input signal to ensure transmission. Since the nerve cell responds by firing an action potential as large as it is capable of, its response may be characterized as 'all or nothing'. Thus, the individual nerve cell is incapable of modulating its output and may in this sense be compared to a flip-flop type device. The fact that a diffusion process takes place at the synaptic terminal indicates that there is a transmission delay in the nerve fiber at every point at which a synaptic terminal must be crossed.

Considering the large amount of data that the brain is capable of assimilating each second, synaptic transmission delay seems to suggest that a large amount of data processing in the brain is likely in parallel rather than in serial form. Not every pulse is passed on in the nerve fiber. The dendritic structure is not limited to interfacing with only one preceding neuron, but rather interfaces with many. The input of a single preceding neuron is rarely sufficient to cause the receiving neuron to fire, and the inputs from several neurons or several inputs from one neuron are required. These summation processes are termed spatial and temporal summation respectively. Thus, it is possible that the inputs from a certain neuron may not be intended to fire the receiving neuron at all, but rather be facilitating and make it easier for other neural inputs to fire the cell. Additionally, a transmitter substance might be such as to

inhibit the firing of the receiving neuron, and its effects would then have to be overcome by several facilitating neurons before nerve impulse conduction would occur. Therefore, each individual neuron's actions are determined by large groups of its neighbors. The summation of the inputs from neighboring neurons at the axon hillock creates a very complex and interrelated continuous voting structure which determines a 'fire' or 'no fire' condition.

The external ionic current flow between the axon hillock and the dendritic structure due to inputs to the neuron is the basis for the electroencephalogram as it is detected at the scalp. The cortex underlying the scalp contains a layered structure with many very specialized forms of neurons. One of these, the pyramidal cell, has a particularly long travel from the dendritic structure to the axon hillock. This cell is the primary source of the surface EEG, receiving inputs from cells in the outer cortical layers and creating ionic current flow to layers far below the surface. Firgure 3 details the process of generation of the EEG. Measuring the potential at the surface with respect to a selected reference point yields a varying electrical signal, the unipolar EEG.

One must pay particular attention to the fact that the EEG is not comprised of the action potential of a single neuron, but of the inputs to many thousands of neurons. These inputs may not be large enough to make the neurons fire, but may rather make them more susceptible to firing. The fact that whole banks of neurons are being facilitated

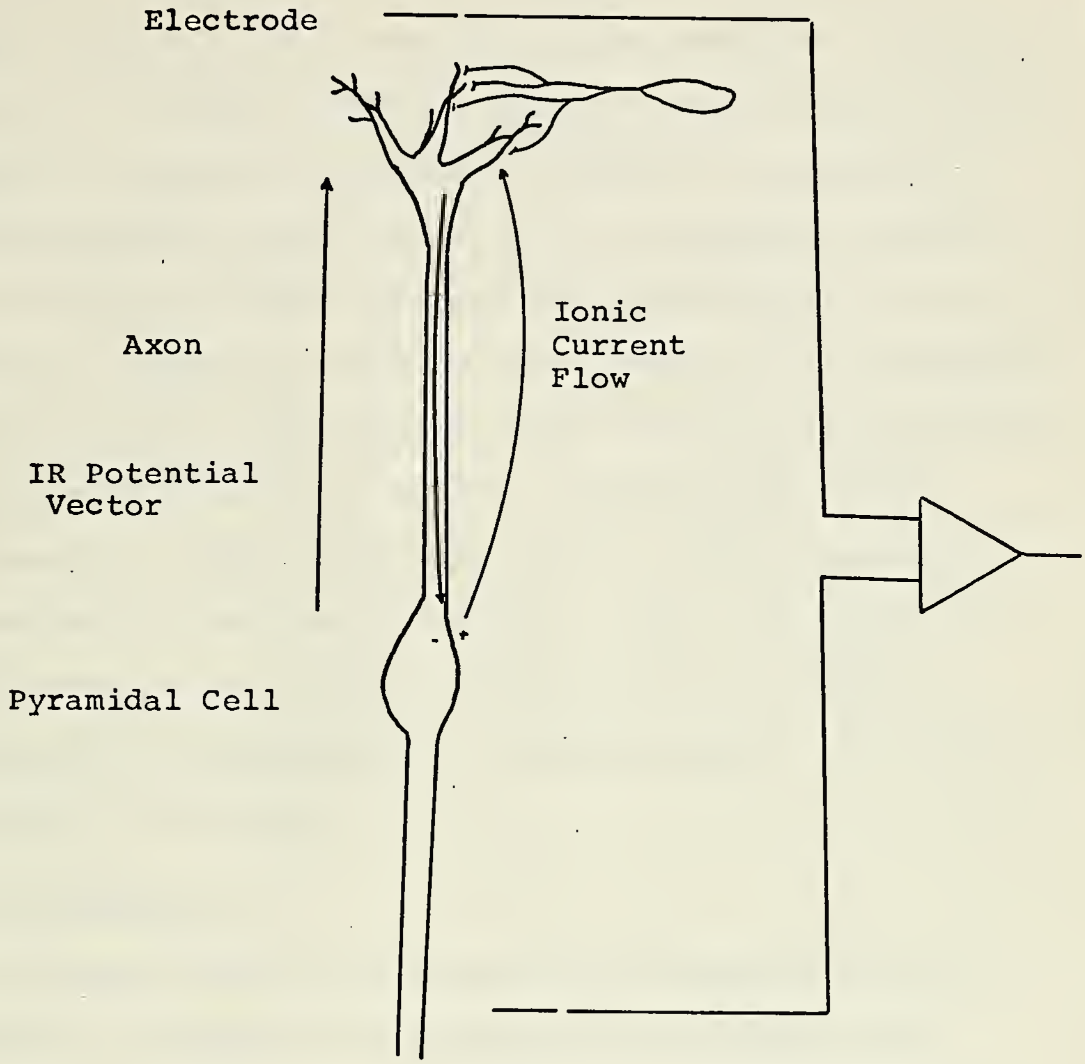

Figure 3. Generation of the EEG by ionic current flow in response to facilitating inputs to a pyramidal cell.

synchronously shows that the facilitating signal is a control device directing the operation of thousands, if not millions of neurons. If one considers the output of a single neuron to be a data bit in the classical flip-flop device of a modern computer, then the facilitating inputs could be likened to processing commands or timing and synchronization pulses. This is a very important conclusion since it follows that the EEG investigators are not looking at actual data bits, but rather at the processing control signals. The optimum performance of the processing groups will most likely be best characterized by the processing signals. When the control signals have been characterized and their functional usage reasonably well identified, it is logical that some portion might be selected for biofeedback to indicate superior or inferior processor performance.

C. EEG RESEARCH

The human EEG is the object of an expanding field of research. Clinical investigation has resulted in new methods of detecting and localizing tumors. Epilepsy can often be detected and classified by EEG abnormalities. New insight into sleep has been gained by comparing EEGs taken during various conditions of sleep such as light sleep, deep sleep, and dreaming. Recent interest has focused on EEG patterns resulting when a subject is presented with an oft repeated stimulus, such as a flashing light or a clicking sound. Averaging the waveforms detected after presentation of a repeated stimulus results in a characteristic

waveform or evoked response. The effect of a slight change in the stimulus is easily observed as a modification of the basic evoked response. Typical types of change in the stimulus have included varying the rate of flash, duration, intensity, and flash train length of a light or sound stimulus; changing the pattern on which a light is shown, and diffusing the focus of a subject as he looks at a visual stimulus.

The research program at the Naval Postgraduate School has a decidedly different thrust than most previous programs. The EEG is taken from the subject during performance of a selected task, rather than during sleep or in a purely restful situation. It is precisely the characteristics of the EEG during useful mental activity which are being investigated. The program goals include identifying major characteristics of the EEG, relating those characteristics to the type of mental activity in progress, and exploring possible applications of the understanding of the EEG so gained. It is important to stress that the program must proceed from one phase to the next. It would be difficult to attempt to find applications for EEG understanding when such understanding has not been adequately developed. Thus, much basic research must be completed prior to applications development.

There are many areas for possible future application of results of the basic research. If superior performance of the cortex processing functions can be detected and displayed back to the subject through biofeedback, it is

hoped that efficient utilization of mental resources can be attained. One area of application would be in feedback reinforcement to an equipment operator advising him of the condition of his mental performance. Two specific types of this application that will be investigated at the Naval Postgraduate School include anti-submarine warfare (ASW) operators and aircraft pilots. Actual ASW grams, strip charts containing signal records indicative of the presence of shipping, have been obtained from P-3 ASW aircraft operating off the Pacific coast of the United States. The EEG from subjects engaged in typical submarine detection tasks is being recorded and investigated.

Many, in fact about 80 percent, of today's aircraft accidents are caused by pilot error. The increasing cost of the airframe, engine, and associated avionics makes the elimination of pilot error the target of a large safety program in Naval Aviation. A simulated cockpit is being designed to allow investigation of the EEG of a pilot engaged in typical flight situations such as navigation, air intercept, and instrument landing approach. It is possible that such investigation may make significant contributions to understanding the man-machine interface involved in flight and similarly complex tasks.

Another area for possible application of EEG investigation is in developing methods for improved selection of candidates for entry into programs demanding complex mental activity. Estimates of the cost of training a pilot to be fully qualified in a jet light attack aircraft are above $500,000 per man. Qualification in more complex

aircraft is corredpondingly more expensive. If some characteristic of the EEG can be linked to a high likelihood of success at a task, then possibly the 'wash-out' rate in training programs can be greatly reduced, with impressive savings in training costs for the Navy.

Construction of efficient training programs and detection of less than optimum training methods is another area for application of EEG research. Monitoring the EEG of a sample of students engaged in a training program might indicate an area wherein less mental activity is required, justifying an increase in the training rate. Conversely, situations might be detected wherein too much information is being presented to the student to allow successful assimilation.

External monitoring of performance is another area of possible application for EEG research. With the increase in equipment performance capabilities, it may well be that the weak link in many systems will be the man operating them. It would do little good, for example, to assign an interceptor capable of multi-target attack to more inbound raids than the pilot is capable of processing. Even the best of pilots have periods of less efficient performance, and without some objective indication,these periods might well go unrecognized.

There is, therefore, much research currently being performed on the human EEG in this country and in others with good reason - the application of results may yield large payoffs in most areas of human mental endeavor.

D. BIOLOGICAL FEEDBACK

Biofeedback may be viewed exactly as any other form of feedback and may be defined as presentation of biological information to the subject from which it was taken with the intention of causing some modification of physiological function or routine. The figure below shows the biofeedback link to a subject under test.

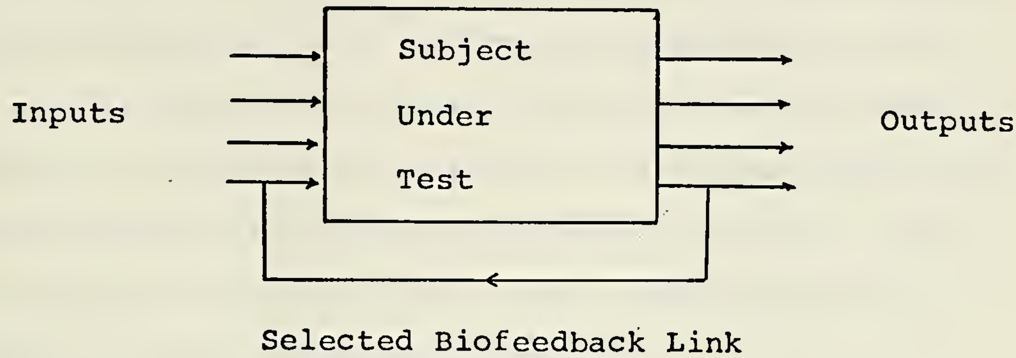

Figure 4. Biofeedback of a selected parameter.

Note that the parameter that is selected for feedback is one of several outputs; it may not be the proper parameter for feedback to attain the desired modification in output. It must also be conceded that the information fedback, even if the correct parameter is selected, is only one of many inputs and may temporarily be overridden by other inputs. Detecting a hostile missile enroute will temporarily have more effect in modifying a pilot's performance than the feedback input. However, not only will the pilot's overall performance likely be better in non-stress situations, but it is hoped that past effective training and

flight experience without biofeedback reinforcement will have made the pilot better able to cope with emergency situations when they arise.

Having determined that the EEG signals being investigated are processing control signals, it still remains to be shown that biofeedback of EEG information does have a likelihood of affecting the performance of the subject. That positive effect is probable is strongly indicated by results attained in other biofeedback experiments which prove that muscles and nervous systems that are normally automatic in function ('involuntary' or 'autonomous') are actually controllable with training and practice. Self control of bodily function has been investigated with increasing regularity in recent years.

Shapiro, Tursky, Gershon, and Stern have shown that systolic blood pressure can be lowered by feeding back a continuous reading to the subject and rewarding him when the reading goes down.

A dramatic success in biofeedback was achieved by Ardyck, Petrinovich, and Ellsworth when they discovered how to solve one of the most difficult problems in teaching speed reading - that of eliminating subvocalization where the speech system tracks what was being read as if it were actually being spoken instead. They measured the electrical activity of the speech muscles during silent reading to graphically illustrate to the students that they were subvocalizing and give them a positive indication when they had ceased to do so. Not only did they meet with success in

eliminating subvocalization, but they did so with startling rapidity. Only one session was required in training, after which the habit never recurred! This is remarkable in view of the long time in which the habit had previously been practiced, and demonstrates the potential effectiveness of biofeedback methods in training. Other experiments have demonstrated control via feedback over salivation, heart rate, urination, kidney function, gastric secretion, and vasomotor responses.

Applications for biofeedback research include such items as correction of improper reflex action in reading by substitution of voluntary control, and control of final neurotic response by learning to recognize precursors to response onset and controlling the initial phases of a neurosis.

There is, therefore, very sound reason to believe that EEG biofeedback will be very successful in causing modification of the subject's responses. It must be stressed again, however, that applications research must be preceded by very investigation into the more basic areas such as characteristics identification and functional association. Once this is accomplished, however, many areas for application of EEG research results and biofeedback techniques are available.

E. EXPERIMENTAL PROCEDURES

1. Environment

Figure 5 diagrams the research equipment arrangement used in the EEG investigations at the Naval Postgraduate School. The subject is placed in a screen room to provide him with a degree of seclusion and to aid in reducing noise introduction into the electrode pickups from RF sources in the area. Noise and light levels are controllable.

2. EEG Input

The EEG is detected by as many as eight surface electrodes and amplified by differential amplifiers designed and built specifically for the low signal levels involved. Electrode placement on the head varies with the type of investigation being performed. A reference input to the differential amplifiers is taken from the lowest portion of the ear lobe. A ground electrode is placed on the collarbone of the subject to isolate the EEG from the relatively strong myoelectric signals from the heart and other body muscles. The amplified EEG signals are then fed to an analog-digital converter and multiplexed for input to the signal processing equipment.

3. Signal Processing

Analysis of the input signals is performed by the TIME/DATA 1923 Time Series Waveform Analyzer. The heart of this system is a Digital Equipment Corporation PDP-11/40 computer, aided by a hardwired Fast Fourier Transform (FFT) algorithm, and additional amplification and data display

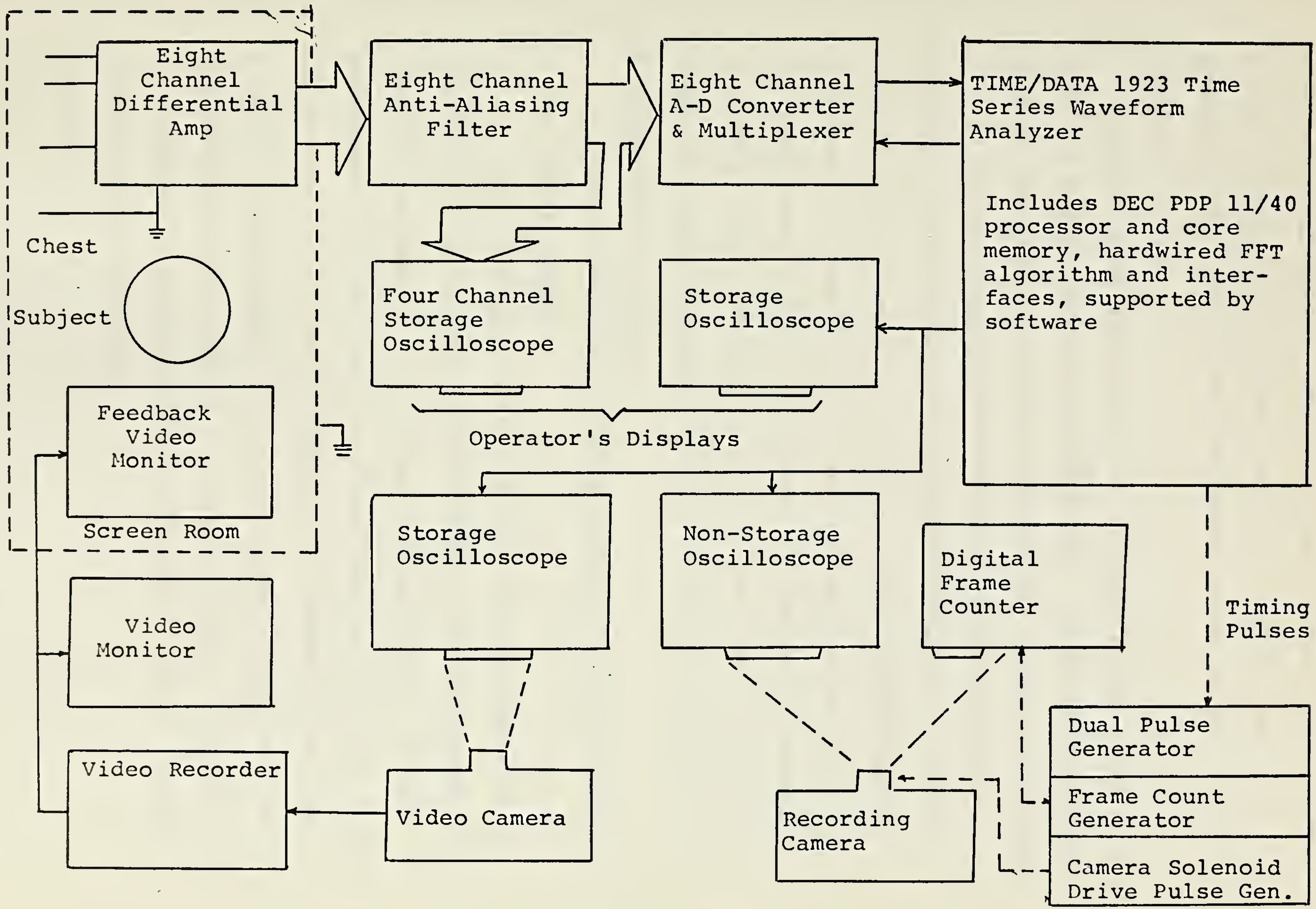

Figure 5. Experimental equipment arrangement

units. A specially designed computer language, TSL (Time Series Language), provides a means of linking subroutine operations to perform data analysis and to control output format.

Although many functions can be performed by this very flexible signal processing equipment, those most frequently used in the research program include FFT, inverse FFT, digital filtering, auto spectral function, cross spectral function, calculation of the transfer function, and waveform averaging. Typically, waveforms are entered in the time domain, transferred to the frequency domain via the FFT algorithm, digitally filtered as desired, processed in either time or frequency domain, and then displayed on output equipment in either time or frequency domain or in a combination of the two.

All data processing takes place on a real time basis.

4. Data Output

The immediate output of data to the observers is usually via two storage oscilloscopes, one displaying the input or raw EEG, and the other displaying the results of processing the EEG. Another output link is fed to a large screen non-storage oscilloscope in a separate room where a motion picture camera is used to make a permanent record. The motion picture camera is controlled by a solenoid that is actuated by a pulse from the TIME/DATA system at the data presentation rate.

5. Data Analysis

Although the hard data record is available only after film processing, the actual data processing of the EEG takes place in real time and is displayed to the observers as it is produced. This is a significant advantage over previous experimental arrangements wherein the data must be taken, recorded, and analyzed by a separate non-dedicated computer system with attendant delays.In real time processing the investigator can devise an experiment to test a hypothesis and modify it immediately for a second run, based upon the results displayed on the storage oscilloscope. Thus, in a matter of minutes a new hypothesis can be formulated and tested. Interesting features of an experimental run can be noted as they occur and further investigated.

After the data film has been returned from development, a thorough analysis of each reel is made. Multiple runs of study, one frame at a time, are required to carefully evaluate each proposed hypothesis. The precise method of analysis depends, of course, on the particular program being used to process the EEG. For instance, in analyzing a simple display of a selected bandpass of the EEG in the time domain (TEG), a first observation of the reel is made to discern recurring patterns. The occurrence of a particularly frequent pattern (e.g. a burst of sine wave or tegule at a given frequency) is then correlated with the subject's status and/or type of mental activity. In order to thoroughly confirm a hypothesis, a painstaking frame-by-frame statistical analysis is often required.

II. DISPLAYS

A. REQUIREMENTS

Proper displays are required to facilitate the flow of information between the various points of the experimental equipment arrangement. Information must be presented to the subject in the form of tasks to be completed and directions to proceed from one phase of each run to the next. The observers must have proper displays for monitoring the progress of each experiment. Processed data must be displayed to the recording equipment. For biofeedback experiments the subject must be presented with a display of his processed EEG. Thus there are a variety of information flow tasks to be performed, each with its own requirements for information display.

B. TYPES OF TASKS

1. Interrupted Tasking

In order to study the subject during mental activity, it is necessary to present him with a task to perform, observe the EEG, and correlate the two. Three basic types of tasks have been presented to the subject - interrupted tasking, continuous tasking, and parameter control via biofeedback.

Interrupted tasking has the following format:

i. Problem presentation

ii. Problem consideration

iii. Answer determination

iv. Rest

This cycle is then repeated many times, giving multiple periods of contrasting mental activity and rest. An example of this type of tasking would be having the subject under test multiply 134 by 62. The numbers must first be multiplied, subtotals added, and an answer indicated, after which the subject returns to rest.

The processing of a period of comparative rest is important to give a reference with which to compare the EEG taken during mental activity. There are significant differences between a resting subject's EEG and his 'working' EEG, among them a lowering of the overall energy level of the working EEG, accompanied by an ordering of the usage of the frequency spectrum. Preferred frequencies of operation are apparently present during the working EEG.

2. Continuous Tasking

Continuous tasking has a different format. The subject is given a problem that is longer in duration and requires a more even level of mental concentration. There is no distinct problem presentation/processing/answer/rest cycle. Rather, the subject is tasked continuously over a period of time. During that period the subject may arrive at one or more decisions.

An example of a continuous type of task in the Navy would be a radar operator scanning a scope and attempting to pick a target out of the noise and clutter. He continuously processes the data displayed before him until he comes to a decision to classify a blip as an actual target. After the

target is recognized it is monitored at the same time that a continued scan for further targets takes place. Since the detection of the first target does not preclude the possibility that a second target may be present, the tasking of the operator procedes on a continuous basis.

A major difference in this type of tasking is that the contrasting period of rest must be taken all at one time, either before or after the task presentation. During this type of tasking, the subject's mental activity can be rather well correlated with the time coincident EEG.

3. Parameter Control Via Feedback

Parameter control is a method of tasking wherein the subject is fed back a certain characteristic of his EEG and is asked to vary or control that parameter. An example of this type of tasking would be feeding back the magnitude of the spectral transform of the subject's EEG and asking him to raise the power level at a selected frequency. This type of tasking has the advantage of showing the subject as well as the investigator the immediate success of the experiment.

C. SPECIFIC TASKS SELECTED

A variety of tasks are available for creating mental activity in the subject. Each task has its own particular utility in bringing out aspects of the EEG, and each task format requires its own dedicated display equipment and methods. The following discussion concerns many of the specific tasks used and the display equipment that has been developed for presenting them.

1. Simple Problem Tasking

This type of tasking is interrupted tasking and consists of having the subject calculate the answer to a very simple problem. Simple problems can be presented using aural or visual means. Aural presentation can be either verbal and direct from the observers or via a pre-recorded tape. Visual presentation can be either via television monitor directly from the problem source or via video taping. The problems selected for presentation usually consisted of arithmetic operations, word definition, synonym or antonym recognition, or uncomplicated algebraic manipulations.

2. ASW-Gram Study

Figure 6 shows an ASW-gram study device that was designed and built to facilitate the presentation of continuous tasking to the subject. An ASW-gram is a plot, frequency versus time, of the sounds emmitted by shipping. These sounds are detected by sonobouys dropped from aircraft. They are transmitted via radio link to a monitoring aircraft and printed out for an evaluator to monitor on a continuous basis. The evaluator attempts to recognize those patterns that are associated with hostile submarines, and upon perceiving such a pattern classifies it as a detection. Upon detection the evaluator notifies a tactical coordinator who then attempts to localize and further prosecute the target using the inputs from other detection systems. The ASW-grams used for tasking the subject are actual plots from P-3 Orion aircraft flying actual ASW patrol missions off the Pacific

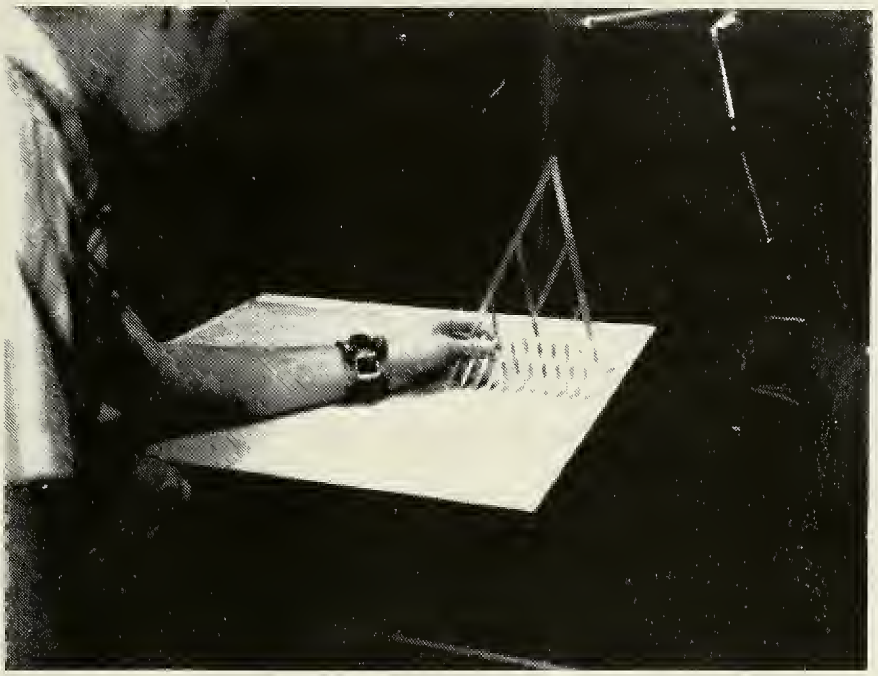

Figure 6. ASW-Gram Study Device

coast of the United States. This not only lends a sense of realism to the task for the subject, but will tend to simplify the transition later from basic characteristics research to applications study.

The ASW-gram study device simulates the actual output plotting of aircraft equipment in that it presents data to the subject at precisely the same rate as it was originally recorded. A two phase induction motor is used to drive the device rather than a DC motor so as to minimize the effects of electromagnetic fields which would introduce noise into the data processing equipment via the electrode leads. The lack of brushes and slip rings further limits noise.

Typical tasking with this device includes determination of input signal frequency, recognition of frequency patterns characteristic of types of shipping, detection of harmonic relationships between frequency traces, and determination of the relative power in each frequency via study of line intensity. The format of information presentation via this device is flexible enough that other tasks of a continuous nature may be presented. Simulated aircraft or ship navigation tasks can be performed by loading the appropriate chart.

An important feature of detection equipment operation is the influence of psychological factors on the operator. False alarm errors and missed detection errors have been carefully analyzed statistically, and by assigning a cost to each type of error optimal rates for each can be determined.

It would be desirable to have detection equipment operators actually function at these rates, and hence study of an operator under various conditions of stress is valuable. It is difficult to simulate the incentives found in a combat environment. However, by artificially setting the desired false alarm and missed detection rates and giving the subject words of approval for meeting them or disapproval for exceeding them, one can get a representation of psychological pressures that is remarkably effective. One is therefore able to study the EEG of a detection equipment operator under conditions of stress or no stress as desired and compare the two conditions for significant differences.

3. Simulated Aircraft Tasking

Simulation of a flight environment provides a rich area for deriving tasking methods of both the continuous and interrupted types. With slight modification biofeedback tasking can also be incorporated in a simulated cockpit's displays.

Aircraft control has been the subject for continuing study in the Bioengineering Option of the Electrical Engineering curriculum at the Naval Postgraduate School. In June of 1973, Charles Boehmer published a thesis titled "A Biophysical Analysis of Aircraft Control Sticks" in which he evaluated various types of control sticks and pilot performance using them in an attempt to find out which was best suited to applications involving remotely piloted vehicles and fly-by-wire systems. In addition, he evaluated the

feasibility of aircraft control through the use of myoelectric voltages. Techniques of myoelectric aircraft control are being further explored under current thesis research by LT Ken Morge, USN. An area for expanded research presents itself with the study of the pilot's EEG. By including myoelectric aircraft control in the tasking of subjects, it is hoped that information may be developed on the interfacings between the brain of the pilot, his muscle system, and the aircraft control system. Further understanding in this area may lead to an improvement in the transfer function of the aircraft's effective equations of motion with consequent improvement in the overall performance of the man-aircraft system as a whole.

In an era of high performance aircraft, the rapid and effective presentation of information to the pilot has become increasingly important. In an attempt to upgrade the information flow rate to the pilot, modern aircraft designers have turned to the heads up display (HUD), which presents information on the status of the aircraft's systems and flight regime while allowing him to continue to monitor the external environment. The HUD is a display group which interfaces with the aircraft's systems to organize, edit, and present information to the pilot. An optical projection superimposed on the pilot's field of view directly ahead of the aircraft allows him to receive the information input without even glancing down into the cockpit. The flexibility of the HUD is displaying information to a subject makes it

an ideal candidate for a tasking device.

An F-111B Vertical Display Indicator Group has been obtained and a simulated cockpit display is being designed around it. This system is of a comparatively advanced design and includes multiple display modes and two display devices, a Direct View Indicator (DVI) and a Projection Indicator (PI) which is actually a heads up display. Figure 7 diagrams the relationships between the components of the display group. Figure 8 is a photograph of the system as it would be viewed by an EEG subject under test. The Projection Indicator combines the reflections of a cathode ray tube and the pilot's forward field of view on a combiner glass. The display signals are focused at infinity, and the pilot does not need to refocus his eyes to intake data. The DVI is physically located directly under the combiner glass. It is a television-like presentation of the vertical situation of the aircraft using a 525 line, interlaced, 60 frame per second raster to produce a high resolution symbolized view of the external environment. It is intended to be used primarily when the aircraft is in instrument flying conditions and visual external reference is not available. It has four modes of operation, each mode being characterized principally by the editing of data and selection of display formats. The four modes are designed to aid the pilot in weapons delivery, precise navigation, and approach to landing; and a complete mission from take-off to landing can be flown with no external references.

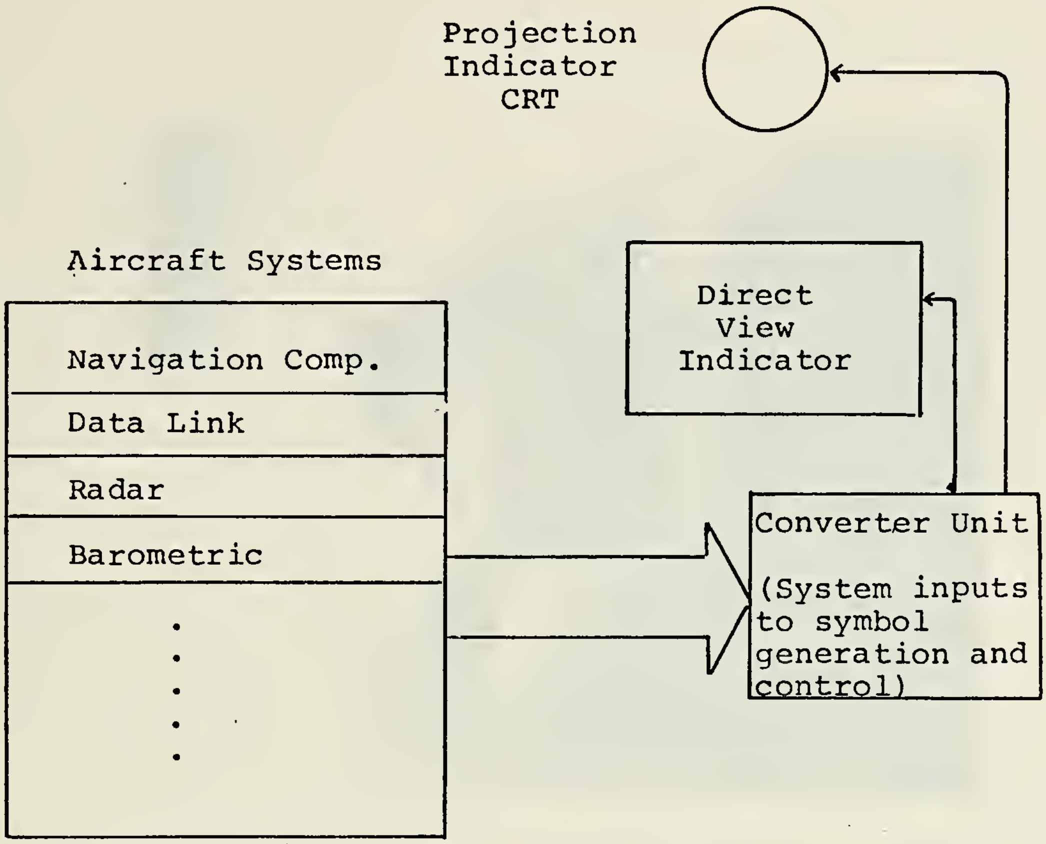

Figure 7. Vertical Display Indicator Group Component Relationships

Figure 8. Vertical Display Indicator Group

Figure 9 diagrams a design for inclusion of the F-111B display group in the tasking for EEG investigation of a subject operating in a simulated flight environment. The control inputs from the subject include either force stick or myoelectric control over the pitch and roll of the 'aircraft'. Simulated engine response is to be controlled by inputs from a nonlinear potentiometer. All control inputs feed into an analog computer for simulation of engine response and aircraft equations of motion in roll and pitch. Yaw is not included initially to simplify inputs and avoid overcomplication of the aircraft equations of motion. The simulation to this point is easily implemented and has flexibility in that the analog computer can be programmed with coefficients for a variety of actual aircraft types.

In order to facilitate inclusion of the display group in tasking procedures, it is intended that initial tasking be limited to operation of those symbols associated with Test Mode 2 of both the DVI and PI. These symbols will allow utilization of the cockpit simulation in a navigation mode. Typical tasking would involve having the subject fly a preplanned course profile with assigned headings, altitudes, and airspeeds. Continuous tasking would be implemented by slowly and continuously introducing random errors into the heading, altitude or airspeed indicators through the observer's inputs to the converter unit. Interrupted tasking can be implemented by giving the subject a simple navigation problem to solve. Figure 10 shows the proposed symbol configuration

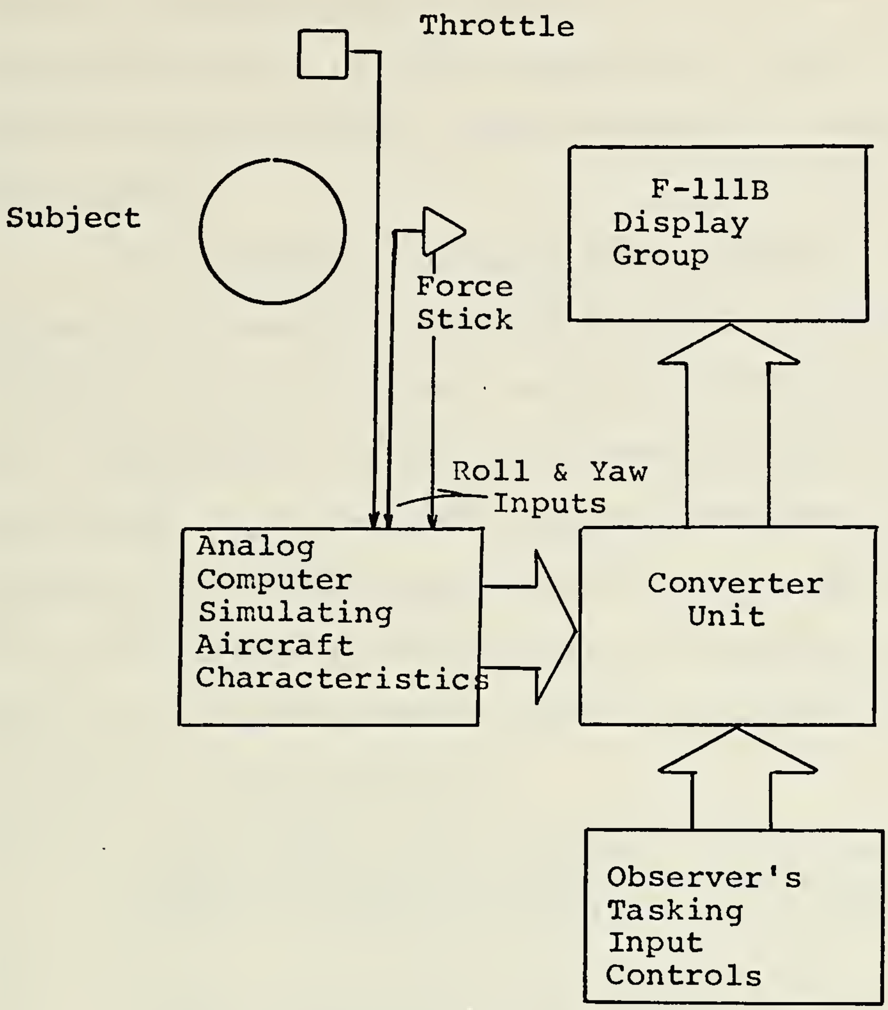

Figure 9. Proposed Cockpit Display Simulation

on the PI, and Figure 11 shows that for the DVI. Table 1 lists the symbol nomenclature for the PI, and Table 2 lists nomenclature for the DVI. Appendices A and B list the symbol functions and control inputs necessary to properly operate the symbols.

As an example in using the appendices, consider Appendix A, symbol #2, Course Pointer. The symbol inputs listed are 240, 250, 270, and 1030. Given the symbol input, it is necessary to refer to the manufacturer's design drawings [Ref. 6] to determine exactly what each input is composed of. DVI input signals are carefully defined in Table 2-1 of Reference 6, and PI input signals are defined in Table 3-1. Turning to the symbol inputs for symbol #2, one finds that the inputs are:

240 - Ground Track (drift angle) - 11.8 V ac 3 wire, 400 cps, synchro signal. Increasing positive sense indicates increasing aircraft drift to the right.

250 - Course Pointer Vertical Displacement - 2.5K ohm 1 watt pot. Excitation voltage ±5 volts dc.
-5 volts indicates - 25 degree down displacement
+5 volts indicates + 25 degree up displacement

270 - Course Pointer ON/OFF - 28V dc = OFF; 0 V dc = ON

1030 - Vertical Offset - 0 V dc = NORMAL; 28 V dc = OFFSET

These signal inputs are delivered to the converter unit of the display group by the aircraft systems, and it will be necessary to synthesize them to operate the symbols properly.

The F-111B Vertical Display Indicator Group is a very flexible system with many more inputs and symbols available than those few selected. Not only is tasking display feasible with this equipment, but biofeedback information can

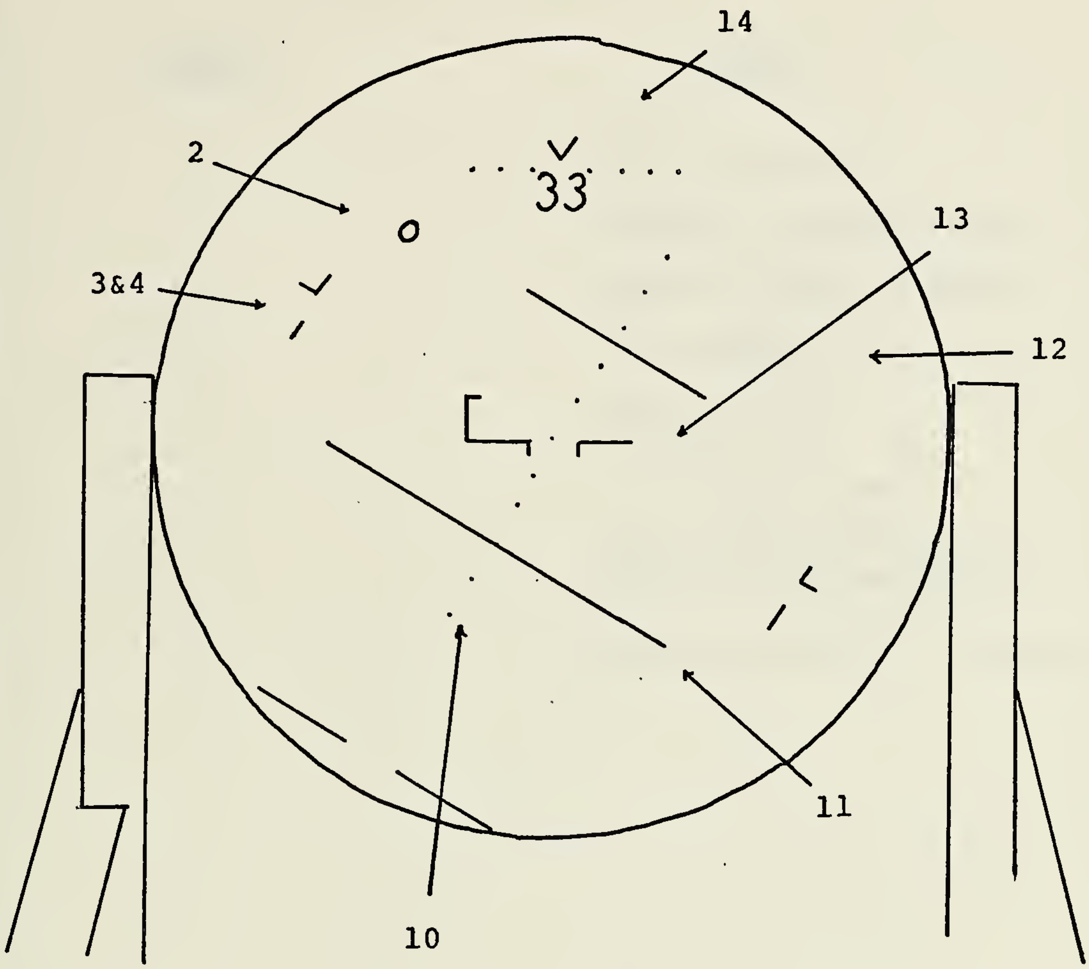

Figure 10. Proposed symbol configuration on projection indicator (PI)

Table 1

PI Symbol Nomenclature

Number	Symbol
2	Course Pointer
3	Command Airspeed Error
4	Command Altitude Error
10	Pitch Ladder
11	Horizon Line
12	$\pm 30^{\circ}$ Pitch Lines
13	Angle of Attack Error and Aircraft Reticle
14	Heading Scale and Pointer

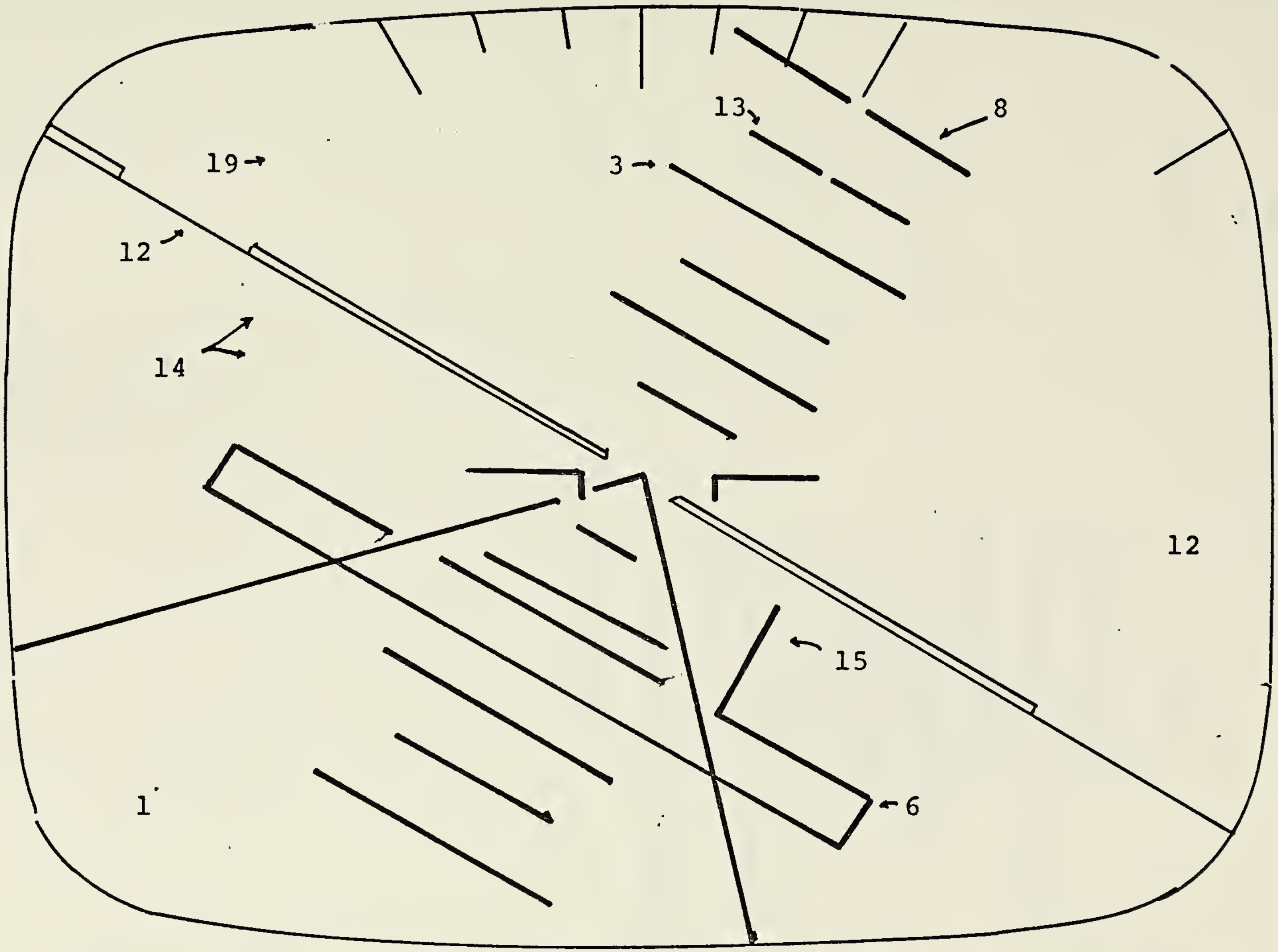

Figure 11. Proposed Symbol Configuration on Direct View Indicator

Table 2

DVI Symbol Nomenclature

Number	Symbol
1	Ground Texture
3	Incremental Pitch Line
6	Time and Range
8	$\pm 30^{\circ}$ Pitch Lines
12	Reference Marker
13	Roll Pointer
14	Horizon Line and Ground Plane
15	Precision Course Vectoring
19	Sky Shading

also be presented by simply dedicating any symbol to a specific biofeedback characteristic. A simple example of this would be activating the ON condition of a symbol upon exceeding a preset amplitude threshold of 20 hertz present in the EEG. This would tell a subject that he is successful in generation of the 20 hertz signal. The display system is, then, flexible with room for growth as further requirements are placed upon it by expansion of the research program.

4. Biofeedback and Parameter Control Tasking

Parameter control tasking imposes two requirements on the experimental equipment. First, appropriate display methods for biofeedback of information are required. Second, data processing must be in real time. Introducing a delay in feeding back the information to the subject could completely nullify a biofeedback experiment. For example, a delay can be introduced between a person's speaking a word and his hearing it by recording him on a tape recorder with a record monitor head slightly after the record head. Taking the output of the monitor head and playing it back to the person recording will render him unable to speak intelligible sentences. The TIME/DATA 1923 Time Series Waveform Analyzer is capable of real time analysis, leaving only the requirement for display equipment capable of presenting biofeedback information to the subject.

There are basically four methods of inputting information to the subject - audio, olfactory, tactile, and visual. Audio feedback suffers from a slow rate of information flow

since any signal coming from an audio amplifier must be delayed until the previous signal has been completed to be meaningful. Combination of two audio signals will not result in accurate input of the two pieces of information that they represent. The two sounds will combine to form a third sound which may represent an altogether different piece of information.In addition, an audio system suffers from the phenomena of accomodation of the nerves in the hearing system. If a desirable characteristic of the EEG is maintained successfully over a period of time, the nerves in the ear will tire or fatigue and cease reporting the presence of the audio biofeedback input unless measures are taken to preclude the fatigue. Placing a single signal on different frequencies would help reduce fatigue of the nerve cells, but would further reduce the information flow rate. A second auditory phenomena is that of tracking or following a specific audio signal to the exclusion of others (as in listening to a friend at a noisy cocktail party). Although this is not too serious in a controlled experimental environment, it would be an obstacle to successful biofeedback in a real life situation where the subject would be required to follow other auditory inputs to function properly (as would a pilot in talking to his controller). The auditory feedback signal would then cease to be an effective input to the subject. The lack of effectiveness of auditory inputs is illustrated by the fact that pilots have been known to land with their landing gear up despite very loud auditory warning signals.

Olfactory inputs suffer even worse than auditory inputs in data flow rate considerations. Sensing of odor and reporting it to the brain is very rapid in man, but presentation of an odor usually involves a diffusion process which is slow. Presentation of more than one piece of information will involve some means of storing and presenting completely different chemicals. Persistence of odors would further lower the data rate, since a second bit could not be sent until the first had ceased transmission (diffused away below a detectable level). The sense of smell also enjoys the phenomenon of accomodation. Even a strong unpleasant odor will pass unnoticed after prolonged exposure.

Tactile inputs suffer from accomodation, but only when the stimulus is rather prolonged and even in intensity. A large amount of information can be presented to a subject via tactile input by stimulating different areas and in different patterns. Experiments are now being conducted with blind persons, attempting to substitute the output of a scanning vidicon tube for eyesight. Reportedly, the gross images of objects can be sensed by tactile inputs (patterns impressed upon the back). Further developments in this field may increase the data flow rate to a point where tactile input may be a viable candidate for a feedback medium.

The most developed sensory system in man is his vision. Hundreds of distinct pieces of information are taken in every second through the visual system. Not only collections of data symbols can be accepted, but also

patterns and color as well, yielding an extremely high data flow rate. Biofeedback presentation in this EEG investigation has been via visual inputs.

A television monitor is used to present the subject with a view of the output of the waveform analyzer. The subject then attempts to control the display. An example of tasking that has been performed in this manner is presentation of the power spectra of the EEG. The subject is then required to raise the power found at a prescribed frequency. Testing of this nature, primarily involving LCDR Ron Jolley and LT Bill Stockslager as subjects, has indicated that with practice the subject is indeed capable of increasing the power at a given frequency and in this sense acts as a sinusoidal generator. Other tasks involved the production of bursts of high amplitude signals or the maintenance of a significant amount of alpha (10 hertz) signals in the time domain EEG.

III CONCLUSION

The EEG research program has required development of several different types of tasks - each with its own requirements for display and control. Study of the EEG under tasking conditions has already yielded a significant amount of information on the characteristics of the human EEG and provided some clues as to how data is processed during problem solution. The capability for storing the entire raw EEG in digital form for multiple processing runs is now being added to the analysis equipment. This will allow even more minute and thorough examination of the EEG than previously possible. One may reasonably expect that new capabilities for analysis will lead to new requirements for tasking of subjects with new display methods. Further study of information display methods is necessary to facilitate the eventual transition of the research effort from basic research to applications. New display techniques will be necessary, for example, to apply EEG research results to the development of optimum training programs and candidate screening for entry into difficult programs. Perhaps adaptations of the heads up display will meet these new requirements, or entirely new display systems will have to be considered.

Appendix A

PI Symbol Control Information

#2 Course Pointer

Function - Indicates aircraft ground track (drift angle)

Symbol Inputs - 240, 250, 270, 1030

#3 Command Airspeed Error

Function - Indicates airspeed error

Symbol Inputs - 102, 103, 350, 370, 700, 160, 390, 480, 1030

#4 Command Altitude Error

Function - Indicates altitude error

Symbol Inputs - 102, 300, 310, 103, 320, 160, 190, 420, 1030

#10 Pitch Ladder

Function - Provides Incremental pitch reference

Symbol Inputs - 1050, 1030, 380, 220

#11 Horizon Line

Function - Provides pitch and roll information

Symbol Inputs - 210, 220, 670, 1030, 380

#12 $\pm 30^{\circ}$ Pitch Lines

Function - Provides pitch and roll reference

Symbol Inputs - 210, 220, 660, 1030, 380

#13 Angle of Attack Error Reticle

Function - Provides angle of attack information and reference

#14 Heading Scale and Pointer

Function - Provides magnetic heading information

Symbol Inputs - 200, 360, 1030

Appendix B

DVI Symbol Control Information

#1 <u>Ground Texture</u>

Function - Simulate simplified quasi-random ground texture

Symbol Inputs - 20, 58, 59

#3 <u>Incremental Pitch Line</u>

Function - Provides incremental pitch reference

Symbol Inputs - 21, 49, 38

#6 <u>Time and Range</u>

Function - Gives pilot time to go, time until in range, and range information

Symbol Inputs - 43, 44, 46, 17, 85, 19, 72, 2, 48

#8 <u>$\pm 30^{\circ}$ Pitch Lines</u>

Function - Provides 30° pitch reference up or down

Symbol Inputs - 21, 66, 38, 8, 11, 20

#12 <u>Reference Marker</u>

Function - Provides reference markers

Symbol Inputs - 65

#13 <u>Roll Pointer</u>

Function - Provides roll information

Symbol Input - 50

#14 <u>Horizon Line and Ground Plane</u>

Function - Provides ground and sky demarcation and pitch and roll information

Symbol Inputs - 21, 67, 38, 8, 11

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In conjunction with the current Bioengineering research program at the Naval Postgraduate School, a study of display devices was conducted. Types of tasking used in electro-encephalographic research were defined, and methods of displaying information in each tasking situation were considered. A special device for display of ASW phonograms was

designed and built. Finally, a Vertical Display Indicator Group from an F-111B aircraft was obtained, and a simulated cockpit arrangement was designed incorporating this equipment. The implementation of this design will provide an advanced format for flight simulation tasking with displays particularly suited to biofeedback.

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A study of display devices for feedback of meaningful information to electroencephalogram subjects.